The NOvA Experiment

Current Status and What to Expect

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NuMI Off-Axis ν_e Appearance Experiment

Long-baseline neutrino oscillation experiment

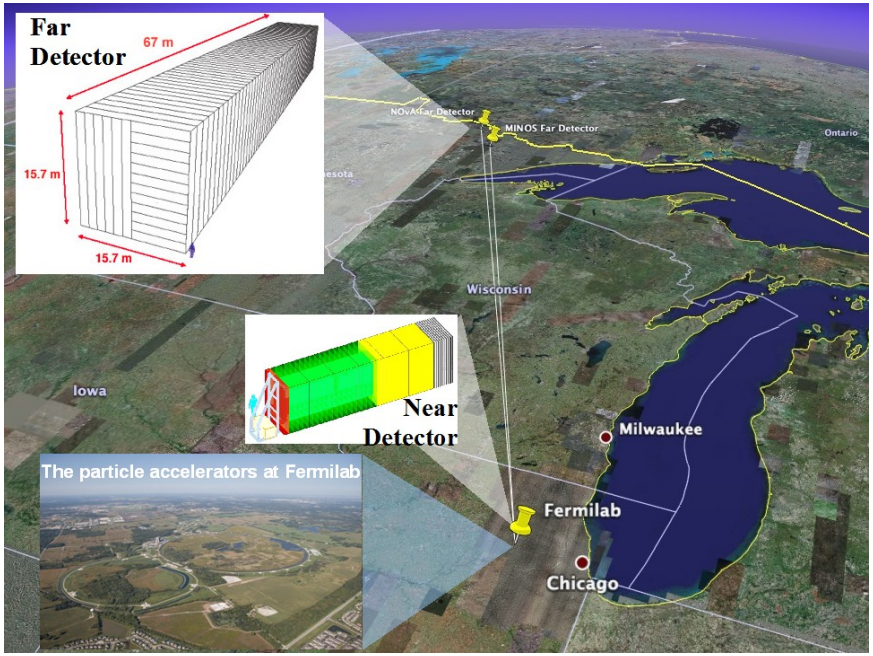
L = 810 km

Oscillations at atmospheric regime

NuMI beam produced at Fermilab

ν_μ and $\bar{\nu}_\mu$ beam modes

$\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_x$ oscillations



Two detector experiment

Near Detector (Fermilab, IL)

Measure beam before oscillations

Far Detector (Ash River, MN)

Measure oscillated beam

Comparison reduces systematics

Currently Under Construction

Physics Goals

3 Categories of Physics Topics

Accelerator ν Oscillation Physics

- Uses Near and Far Detectors

Accelerator ν Near Detector Physics

- Cross-sections

Non-accelerator Physics

- Supernova ν
- Monopoles

Physics Goals

3 Categories of Physics Topics

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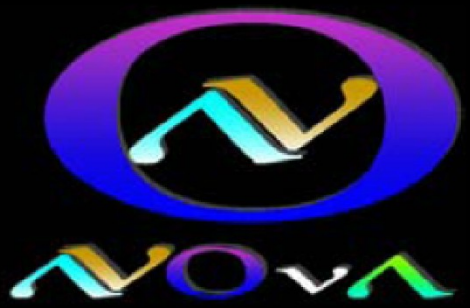

Physics Goals of NOvA

Physics Goals

Measure elements of PMNS matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}\, e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}\, e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Notation: $c_{ij} = \cos(\theta_{ij})$, $s_{ij} = \sin(\theta_{ij})$

Matrix parameterized by 3 angles (θ_{12}, θ_{13}, θ_{23}) and 1 CP-violating phase (δ)

Physics Goals

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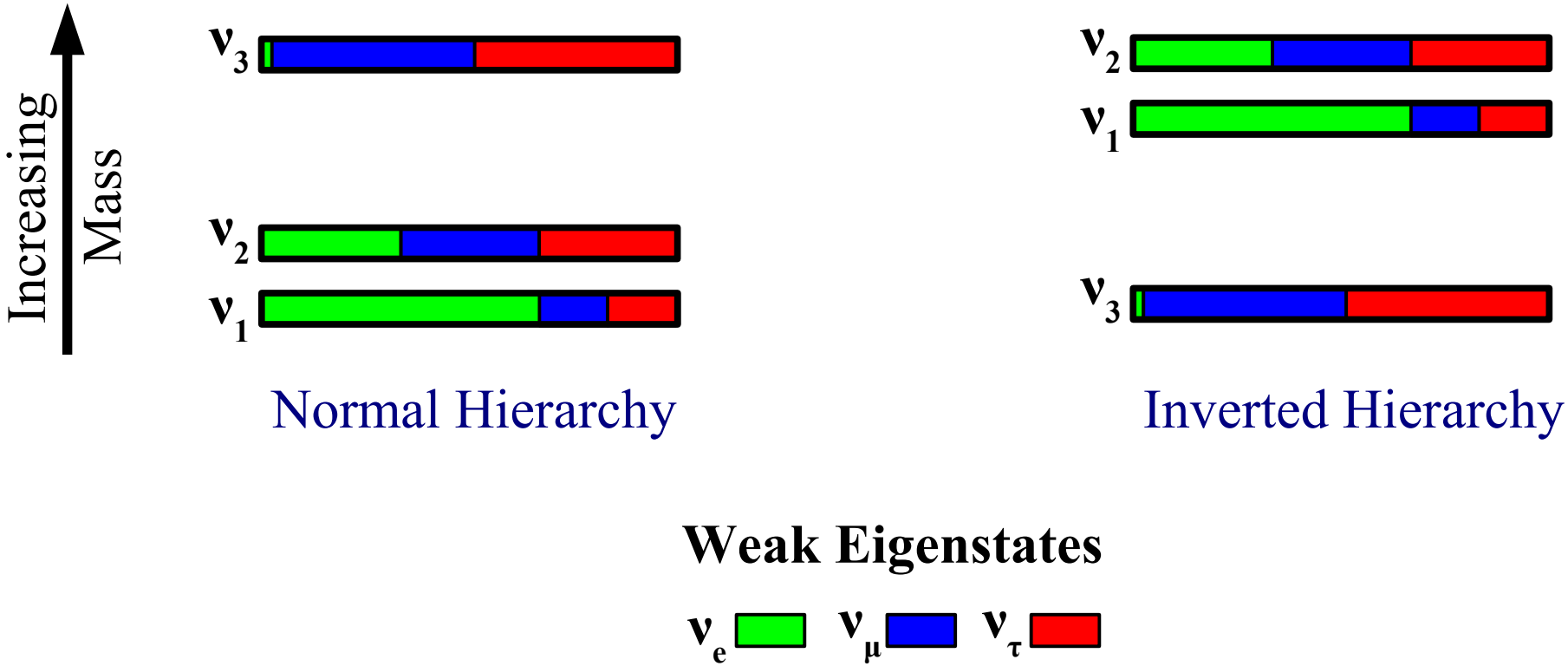
Matrix parameterized by 3 angles (θ_{12}, θ_{13}, θ_{23}) and 1 CP-violating phase (δ)

NOvA will make measurements of:

θ_{13}, θ_{23}, and δ

Physics Goals

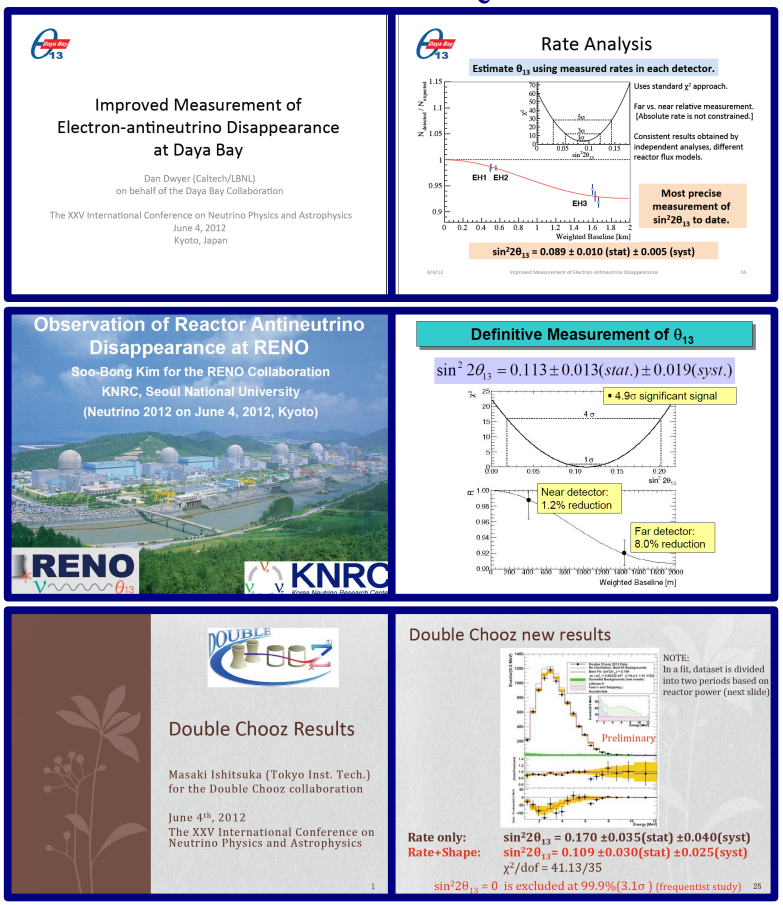
Determine the Mass Hierarchy



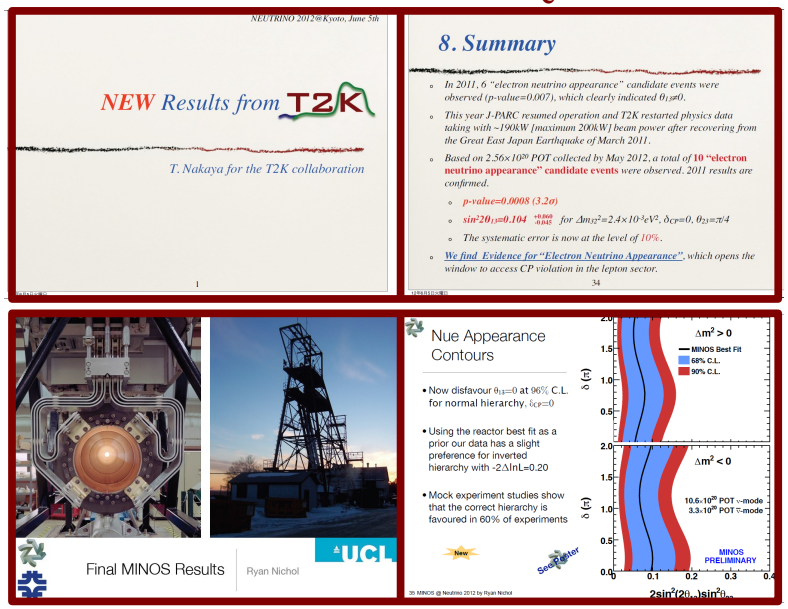
What's Known

Nonzero θ_{13} discovered this year

Observed in reactor $\bar{\nu}_e$ disappearance



Evidence in accelerator ν_e appearance



Combined reactor measurements

$$\sin^2(2\theta_{13}) = 0.0982 \pm 0.0131$$

Great news for NOvA experiment!

Physics Goals – ν_e Appearance

Measure $\nu_\mu \rightarrow \nu_e$ appearance

Leading order probability (in vacuum)

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2\Delta$$

$$- \alpha \sin 2\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \Delta \sin\Delta \sin\Delta$$

$$+ \alpha \sin 2\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \Delta \sin\Delta \cos\Delta$$

$$\alpha = \Delta m^2_{21} / \Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E)$$

Physics Goals – ν_e Appearance

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$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E)$$

Appearance probability is sensitive to:

θ_{13}, δ, octant of θ_{23}

Physics Goals – ν_e Appearance

Measure $\nu_\mu \rightarrow \nu_e$ appearance

Leading order probability (in matter)

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$
$$- \alpha \sin 2\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$
$$+ \alpha \sin 2\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$

$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E) \qquad A = G_f n_e L/(\sqrt{2}\Delta)$$

NOvA over a very long baseline (810 km)

A lot of electrons for ν_e to interact with

Matter effects alter probability

Sensitive to Mass Hierarchy

Physics Goals – ν_e Appearance

Measure $\nu_\mu \rightarrow \nu_e$ appearance

Leading order probability (in matter)

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$

$$\oplus \alpha \sin 2\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$

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$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E) \qquad A = \ominus G_f n_e L/(\sqrt{2}\Delta)$$

Sign flip for ν and $\overline{\nu}$

Constrain parameters more by contrasting probablity for ν and $\overline{\nu}$

NOvA Run Plan
3 year ν
3 year $\overline{\nu}$

Physics Goals – ν_μ Disappearance

Measure $\nu_\mu \rightarrow \nu_\mu$ disappearance

Leading order probability

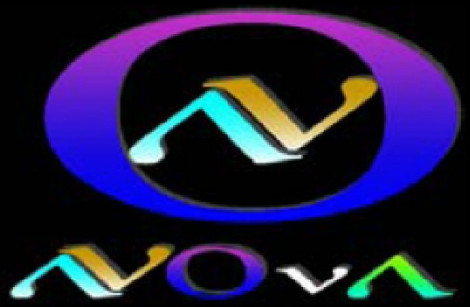
$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2(2\theta_{23})\sin^2(1.27\Delta m^2_{32} L/E)$$

Measurements

$|\Delta m^2_{32}|$

$\sin^2(2\theta_{23})$

Potentially determine if θ_{23} is non-maximal



How NOvA will work

Accelerator and NuMI Upgrades

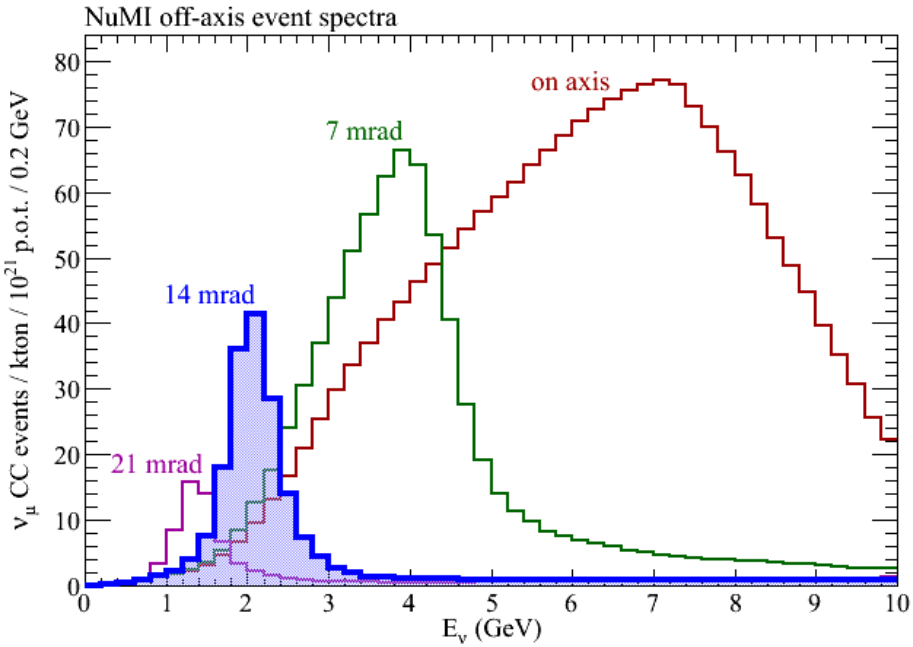
Taking the NuMI source from ~350 kW to 700 kW

- Year-long accelerator shutdown underway (since May 1)
- Turn Recycler from antiproton to proton ring
- Shorten Main Injector cycle from 2.2 seconds to 1.33 seconds
- Overhaul of NuMI target station for 700 kW running
  - Water cooling upgrades for higher power

Beam to return Spring 2013.

Six month ramp-up to 700 kW.

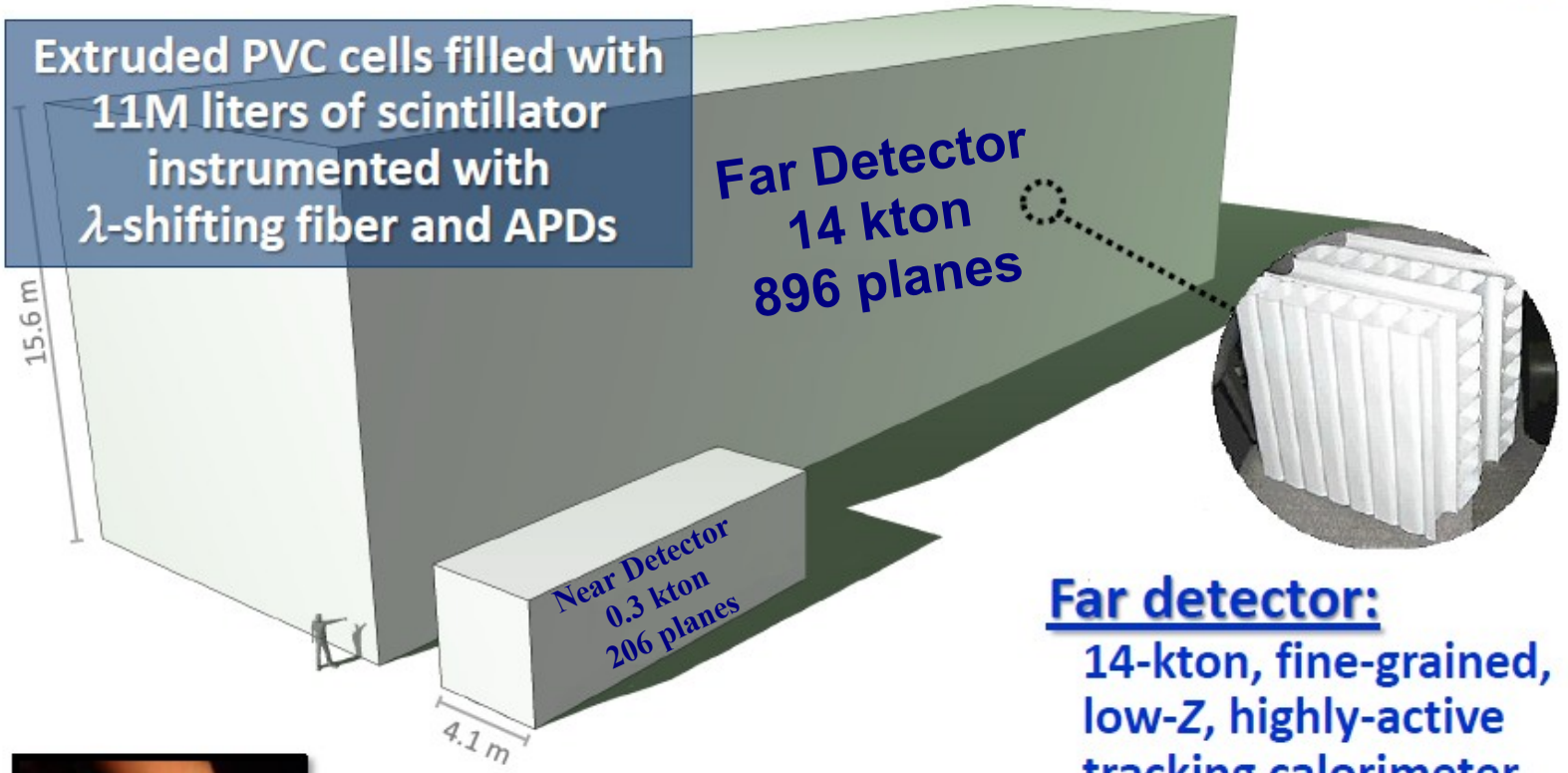
NOvA is at 14 mrad off-axis angle producing a narrow E_ν spectrum at 2 GeV

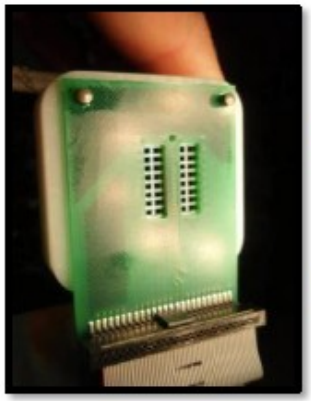


NOvA Detectors

Extruded PVC cells filled with 11M liters of scintillator instrumented with λ-shifting fiber and APDs

Far Detector
14 kton
896 planes

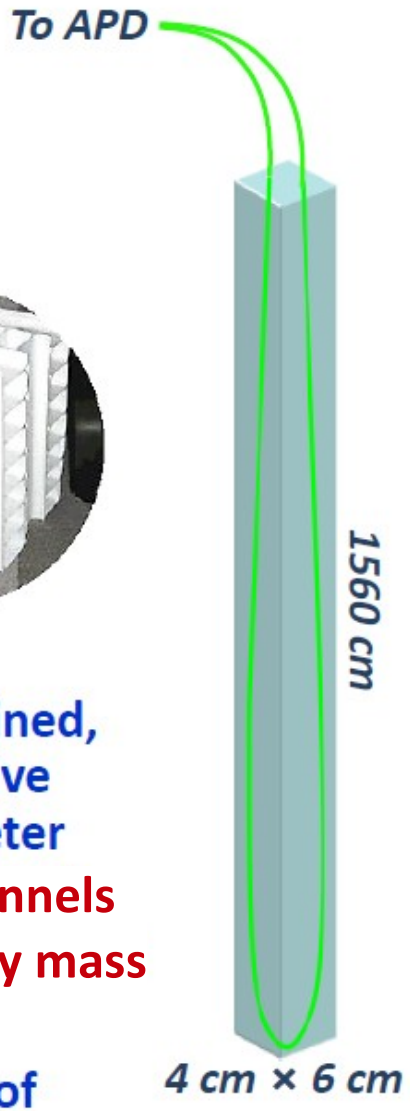




32-pixel APD

Fiber pairs from 32 cells

A NOvA cell



Far detector:

14-kton, fine-grained, low-*Z*, highly-active tracking calorimeter

340, 000 channels

77% active by mass

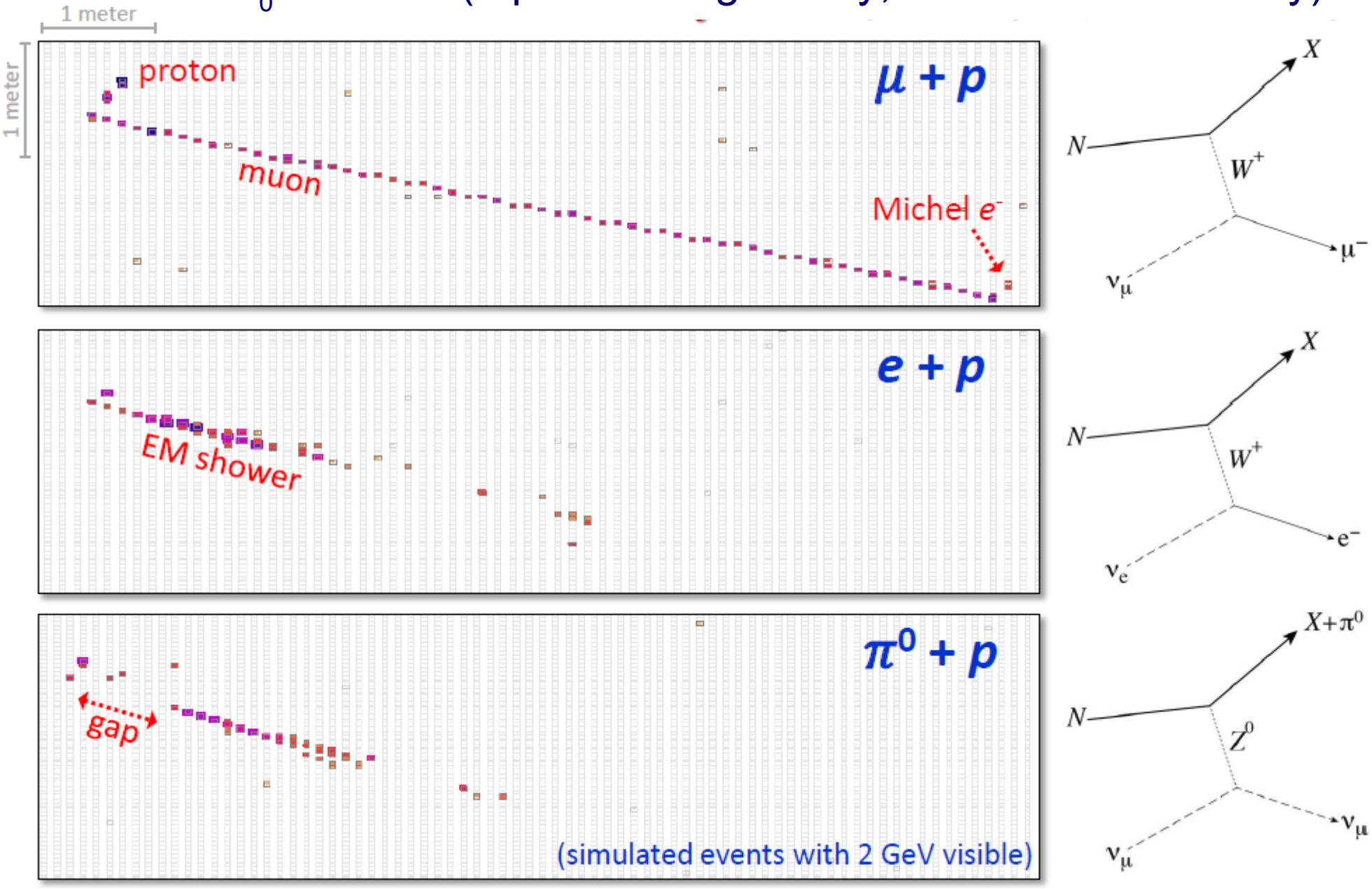
Near detector:

0.3-kton version of the same

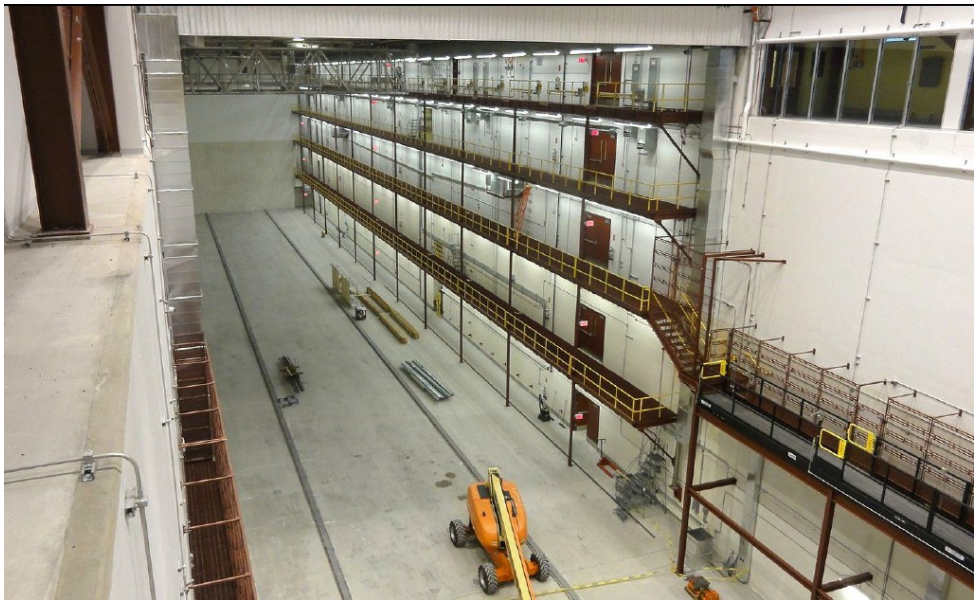
18, 000 channels

Event Topologies

X_0 = 38 cm (6 planes longitudally, 10 cells transversely)



Far Detector Construction Underway

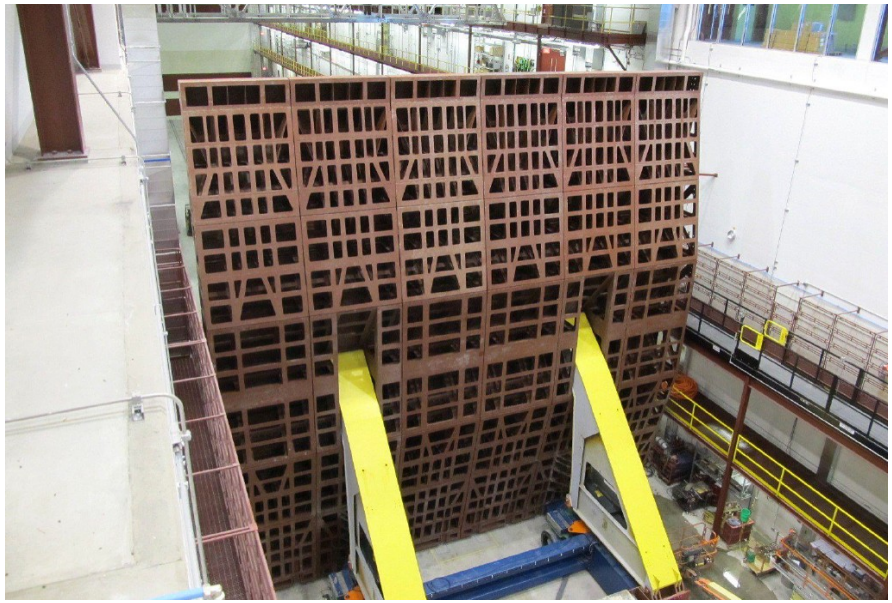


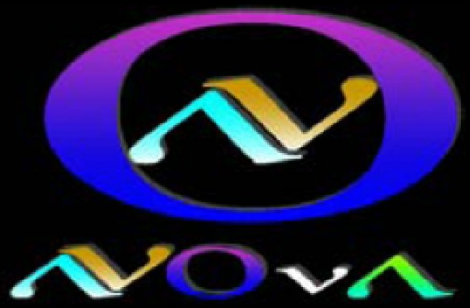
Block Pivoter
- Stands Block Up
- Moves it to end of hall

1st Block installed September 10th

5 blocks up as of Dec 6th

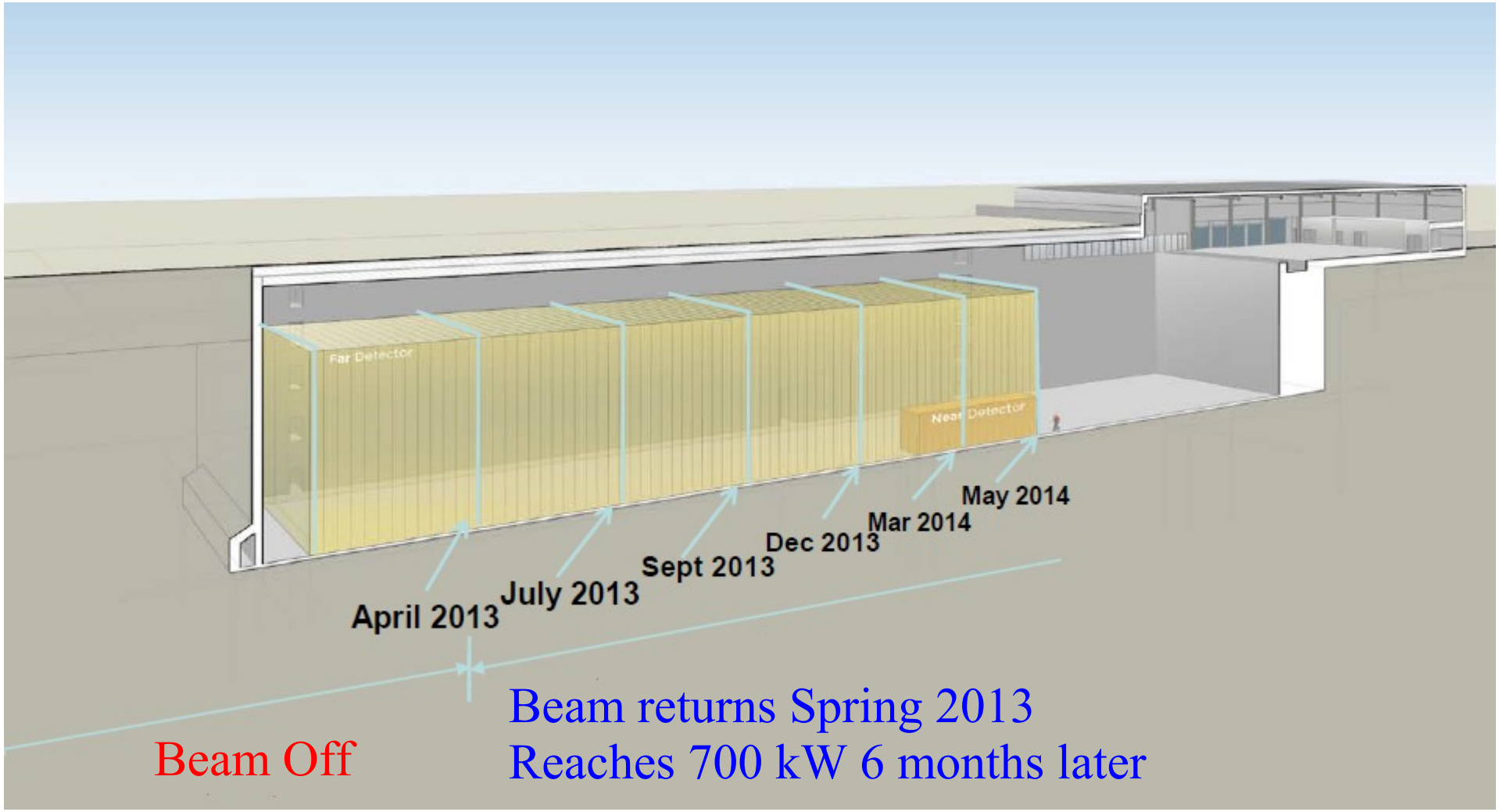
Began filling modules with scintillator Dec 11th (over 10k to go...)



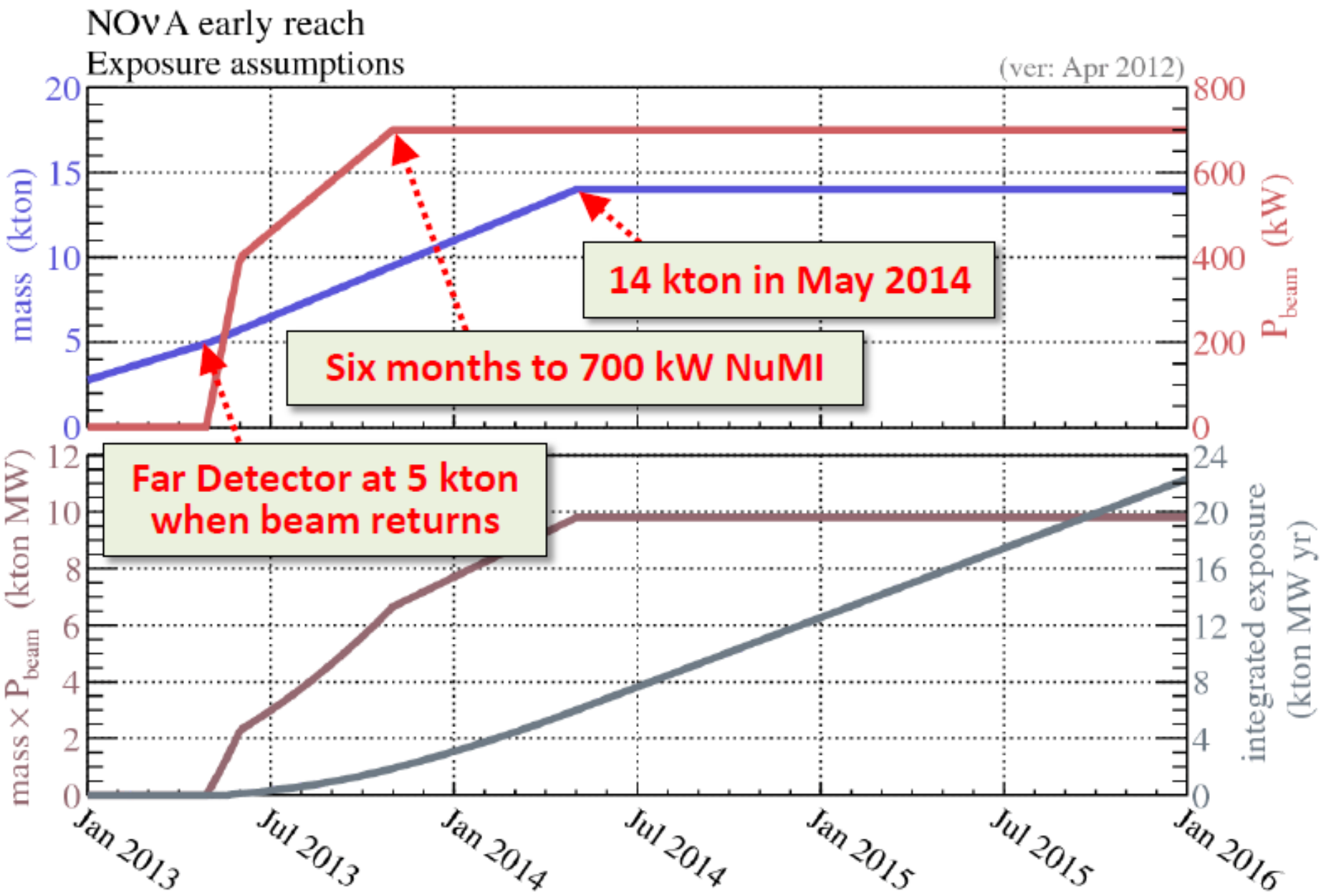


NOvA Sensitivities

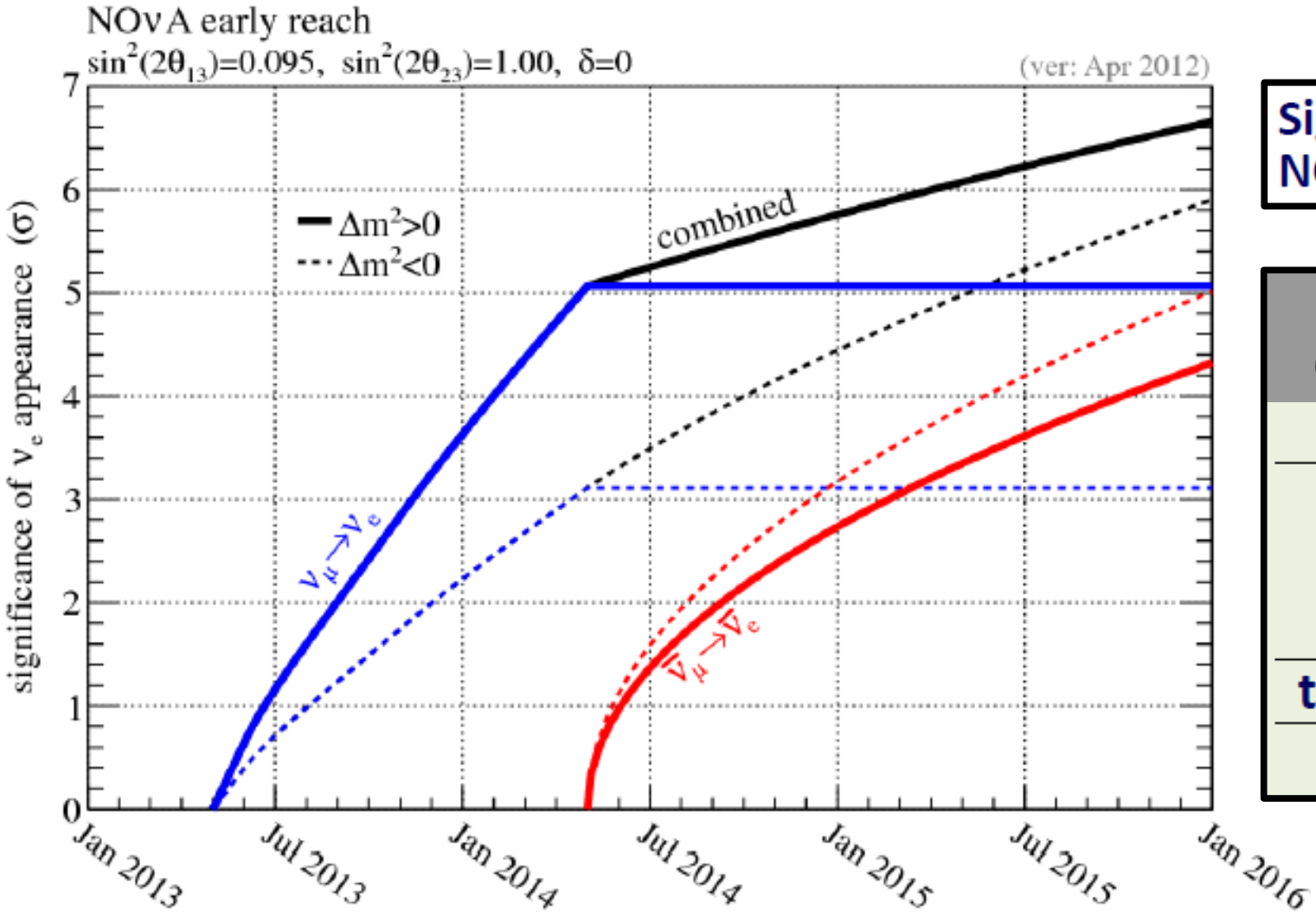
Schedule


Far Detector
Near Detector
April 2013
July 2013
Sept 2013
Dec 2013
Mar 2014
May 2014
Beam Off
Beam returns Spring 2013
Reaches 700 kW 6 months later

Schedule


NOνA early reach
Exposure assumptions
(ver: Apr 2012)
mass (kton)
P_{beam} (kW)
14 kton in May 2014
Six months to 700 kW NuMI
Far Detector at 5 kton
when beam returns
mass × P_{beam} (kton MW)
integrated exposure
(kton MW yr)
Jan 2013
Jul 2013
Jan 2014
Jul 2014
Jan 2015
Jul 2015
Jan 2016

Sensitivity with Time

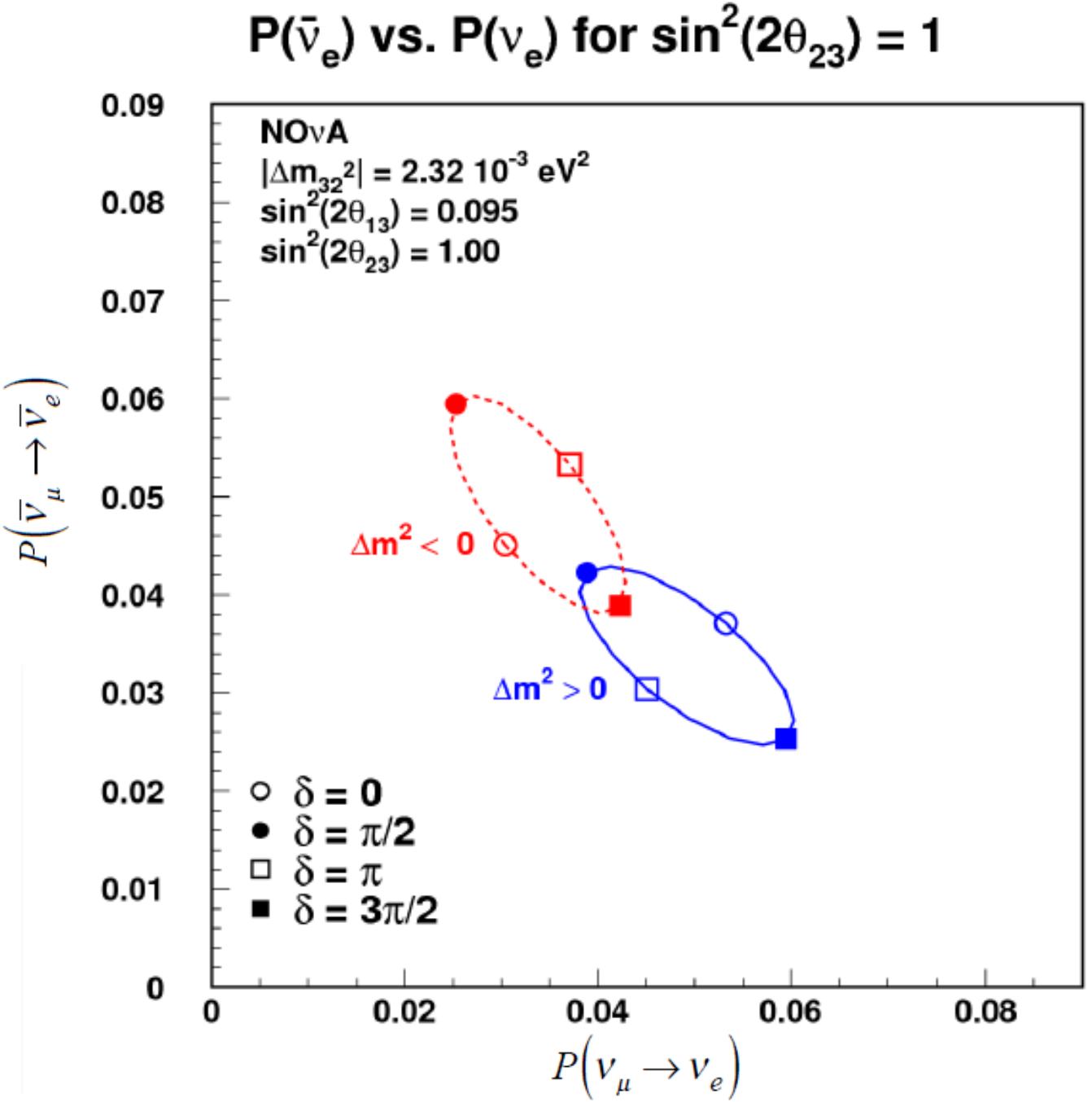


Signal efficiency: 45%
NC fake rate: 0.1%

Event Yields
6 year Run Plan

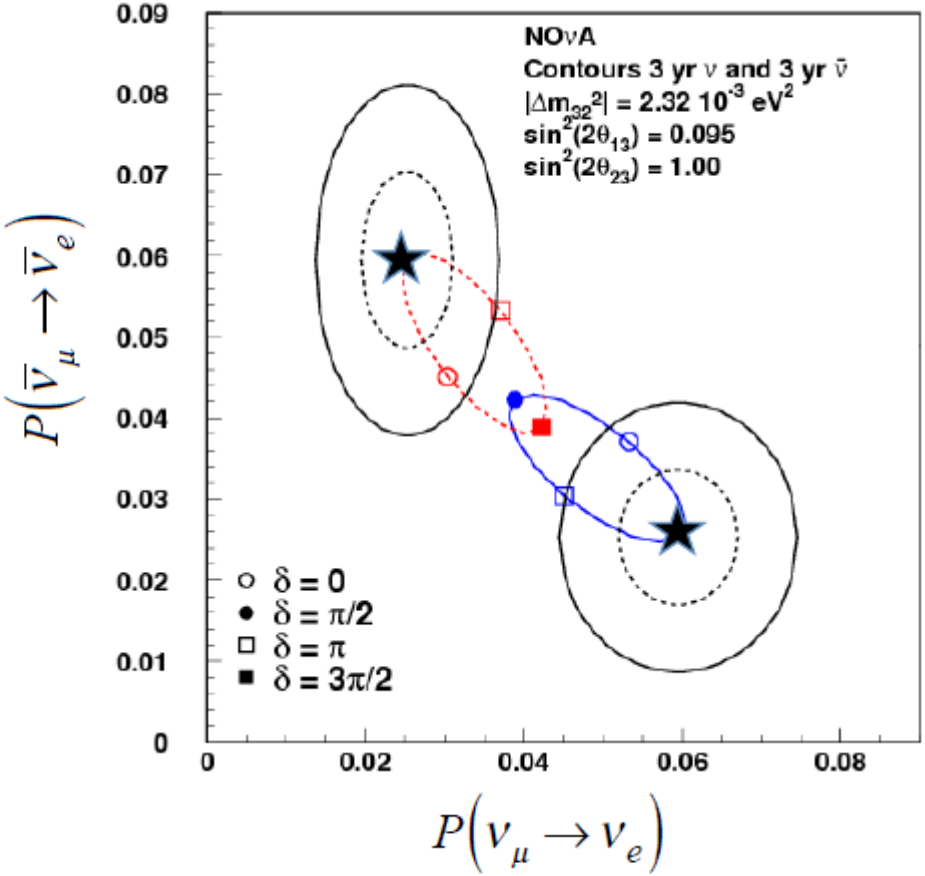
beam = ν	ν	$\bar{\nu}$
NC	19	10
ν_μ CC	5	<1
ν_e CC	8	5
tot. BG	32	15
$\nu_\mu \rightarrow \nu_e$	68	32

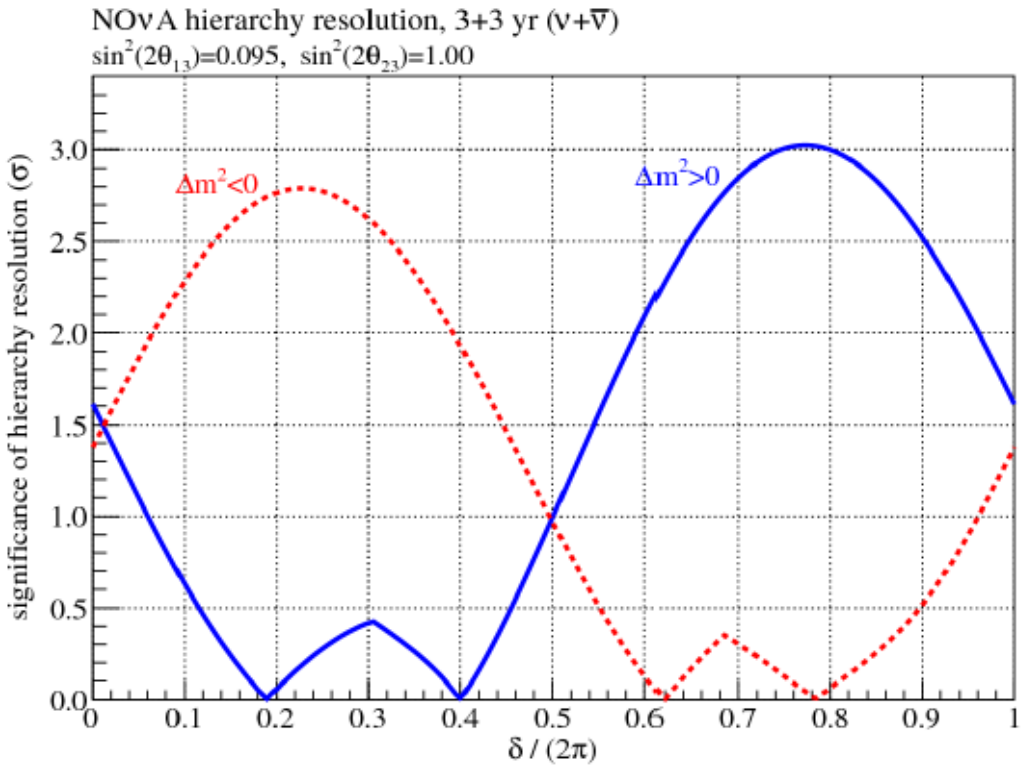
Why run with ν and $\bar{\nu}$



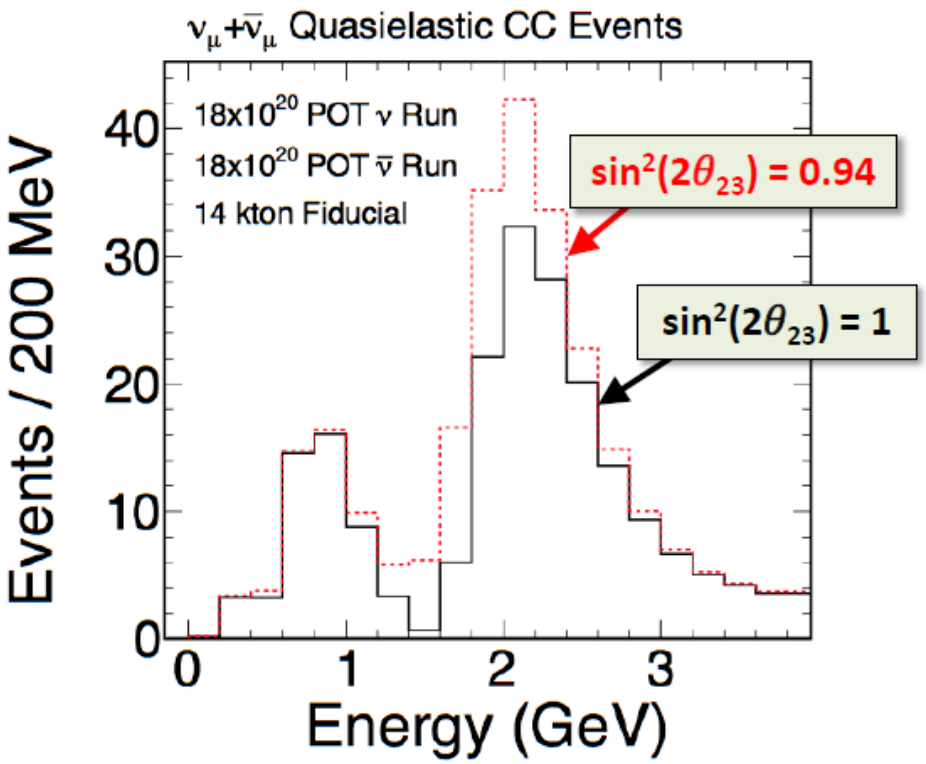
Mass Hierarchy Resolution

1σ and 2σ contours for
2 example measurements

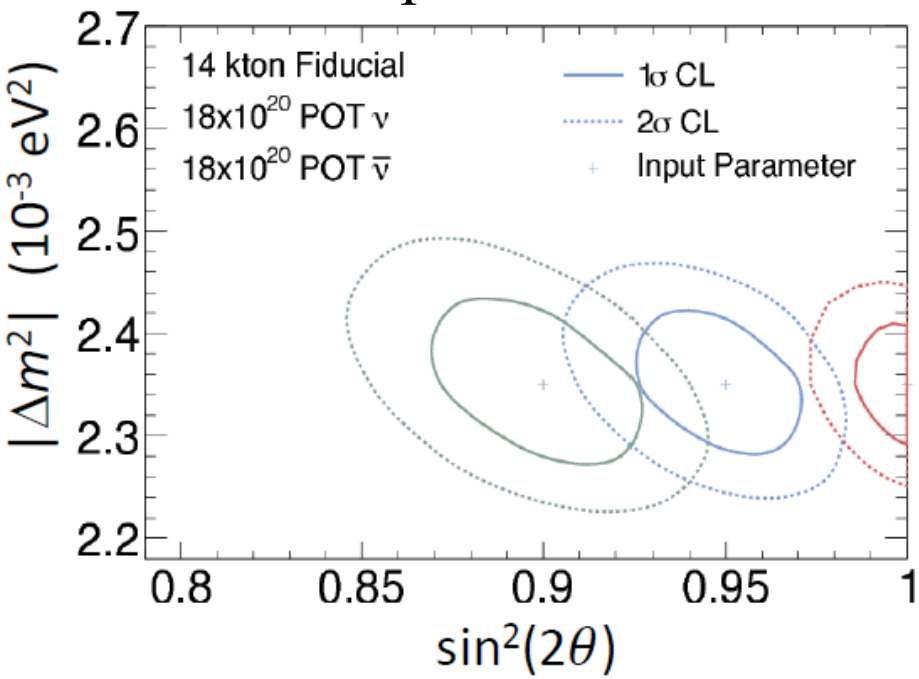




θ_{23} Non-maximal?



3 example measurements



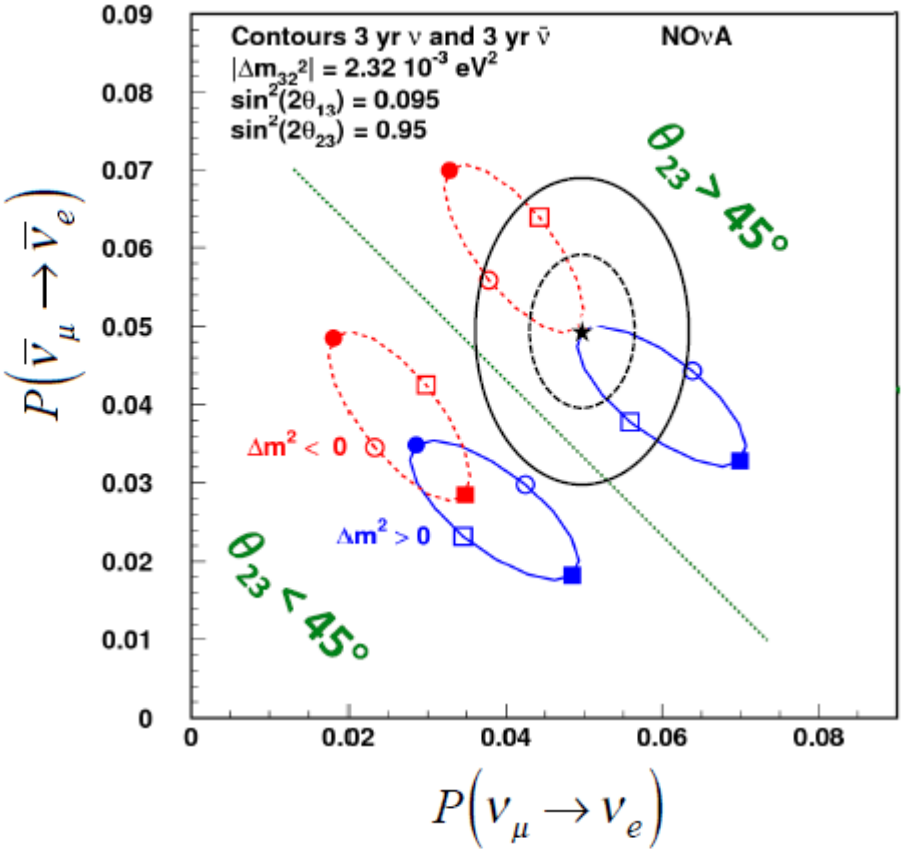
Assumes 4% energy resolution
100% signal selection
100% background rejection

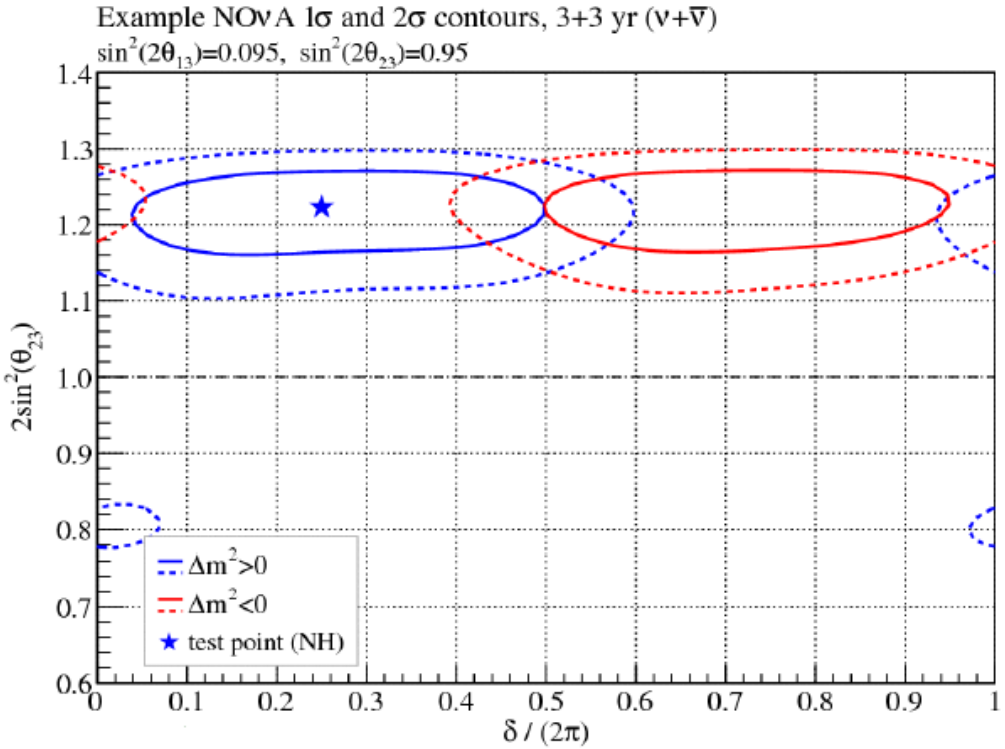
θ_{23} Octant Resolution

$$P(\nu_\mu \rightarrow \nu_e) \propto \sin^2 2\theta_{13} \sin^2 \theta_{23}$$

Depends on $\theta_{23} > 45°$ or $\theta_{23} < 45°$

1σ and 2σ contours for
1 example measurements





Summary

Construction Underway

- Assembling Detectors
- Upgrading Beam

First data Spring 2013

NOvA could potentially answer remaining neutrino questions:

- What's the Mass Hierarchy?
- What's δ?
- What's $(\theta_{23}-45°)$?